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CORNING GLASS WORKS

ELECTRO-OPTICS LABORATORY

RALEIGH, NORTH CAROLINA

IMPROVED SCREEN FOR REAR-PROJECTION VIEWERS

Technical Reports No. 18 and 19

Date - March 3, 1967

Period Covered - January 6, 1967

to

March 3, 1967

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ABSTRACT

This report summarizes the optical properties of additional samples of Corning Glass Works materials. Some of the high-index glasses with low-index scattering centers have been measured and appear promising.

Prototype rear projection screens of Fotoform[®] glass measuring 8" x 10" are being fabricated. Work is continuing on making lenticular screens from Fotoform[®] glass, however problems have been encountered in attempting to redissolve the crystalline phase after the lenticules have been formed and etched.

Three techniques for fabricating large rear projection screens from glass-ceramic materials are discussed along with a novel lenticular screen which is particularly insensitive to ambient light.

TECHNICAL REPORTS NO. 18 AND 19

I. Materials

A. Glass-Ceramics

1. New Materials

We have measured additional samples of glass-ceramic materials. The relevant optical data is summarized in Table A-1 and curves for T_{45} vs. axial gain are given in Figure A-1. The data and curves describing the scattering functions appear in data appendix 3.

Samples of the AW and AX series are of a high-index glass and are expected to be good screen materials. For the most part, these samples either did not have the optimum particle size or the particle concentration was not within acceptable limits. Electron micrographs are being made of these materials to determine their physical properties and remelts will be made to improve these materials.

Electron micrographs have been prepared of samples AS-4 and AS-9 and are shown as Figures A-2 and A-3; the white bar represents one micron. The average particle size is .14 microns for sample AS-4 and .28 microns for sample AS-9, the latter being very close to desired value. Figure A-4 shows a micrograph of high-index particles ($n \approx 2.0$) in a transparent glass ($n \approx 1.5$). The oblique illumination is apparent, and measurements must be scaled to the ellipse representing 4 microns, depending on the diagonal along which the measurements are made. Particle size in this sample is around 0.46 microns.

2. Screen Fabrication

Because of the impossibility of fabricating screens larger than 6" x 6" by mechanical grinding and polishing, other techniques are being investigated. The most straightforward approach is to grind the glass-ceramic into a powder, mix this with a plastic resin, and spray or otherwise deposit the mixture onto a clear

substrate. Modification of the scattering properties of the glass-ceramic materials will occur; the degree, depending upon the relative refractive index of the ceramic powder relative to the embedding resin.

Investigations using an ordinary glass powder and a resin are being conducted to determine the suitability of this approach. Following this work, a glass-ceramic powder will be used and screens measuring 12" x 12" will be made using different sizes of the ceramic particles provided this technique is suitable.

A second approach which should give even better screens and be easier to fabricate has been initiated. It consists of forming very small spherical beads from a "green" glass-ceramic. The beads are then cerammed and sized. As before, a particular size can be mixed with the resin and sprayed onto a clear substrate forming a thin layer. They can also be directly applied to a treated surface which will bond the bead to it. At present, the glass beads are being made and sized.

A third approach is to redraw a sheet of green glass-ceramic into ribbon. This technique would give very thin ribbon up to 1" to 2" in width. The strips could then be laid side by side on a substrate to give the necessary screen size. An attempt has been made to redraw a plate of the green glass-ceramic AS-9. Because of the redrawing temperature, cooling rate, and basic glass properties, the glass devitrified during the redraw; making it impossible to control the crystal characteristics. Other glass-ceramics will be tried; however, this is a typical problem associated with the reforming of glass-ceramics and will most probably be encountered with many of the other glasses.

B. Fotoform Glass

1. Thin-Layer Material

Optical and physical data for these samples have been measured. Figure A-5 shows the correlation between axial gain and the crystal layer thickness. The thickness of the best samples lies

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between 150 and 300 microns. Some 3" x 3" samples have been made for evaluation; however, to better evaluate these materials, we are now preparing some 20" x 20" screens. Delivery is expected in 4 to 6 weeks.

2. Volume-Scattering Material

These samples are coded AV-1 through AV-11 and look quite acceptable as screen materials. As can be seen from Figure 1, these materials have the predicted efficiency. With values of axial gain between 1.5 and 2.4, they exhibit very small variations in brightness over the $\pm 45^{\circ}$ viewing angle.

Samples of this glass have been prepared and are being ground into powder. From this some 12" x 12" screens will be fabricated and made available for further evaluation. Optical properties of the bulk glass will be compared with those of the finished screens to determine how much change the fabrication process has produced. At the same time, screens made up of transparent glass powder will be prepared and compared with screens containing ceramic powders to determine the influence of the refractive-index difference between the ceramics and the resin.

C. Lenticular Screens

1. Lenticular Plate

This is presently being redrawn into ribbon and, provided the plate does not shatter during redraw, some preliminary results should be available next period.

2. Fotoform[®] Glass

We have had mixed success with this material. It was found that lenticules could be formed quite easily; however, exposing and developing the lenticular image in the glass produces crystals about 50 Å in size which are necessary if it is to be etched. After the lenticular pattern is etched into the glass this crystal structure must be removed. This is because the crystals occur throughout the thickness of the screen and significantly

degrade resolution. Several attempts to redissolve this crystalline structure have been tried but without success. Work on this problem is continuing.

II. Theoretical Investigations

A. A New Type of Lenticular Rear Projection Screen which is Insensitive to Ambient Light

A very efficient lenticular screen is described in a 20-year-old French patent (FP 959,731). The screen is constructed as shown in Figure 1, and is made of a transparent substrate on which a thin

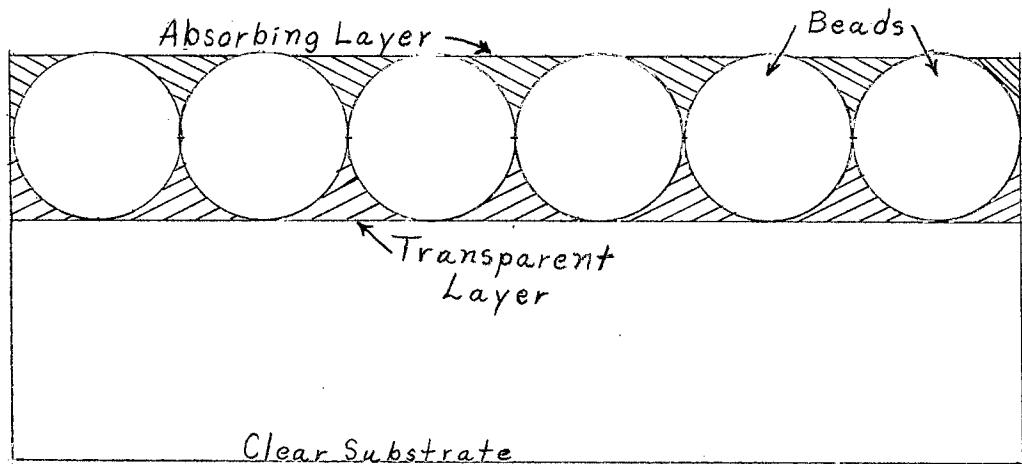


Figure 1. Organization of the Lenticular Screen

layer of a transparent plastic material is poured. The glass beads are then deposited such that they are half embedded in the plastic. After the plastic has set, a second layer containing an absorbing material is poured over the beads until they are "almost" covered except for a very small region at the top; this plastic is then allowed to harden and the screen is complete.

Light from the projector passes through the substrate and is focused through the small openings at the ends of the glass beads and emerges into the viewing area. Ambient light incident from the viewing side is almost completely absorbed by the dark opaque layer and therefore does not degrade the projected image. The resolution limit of such a screen is given approximately by the reciprocal of the bead diameter;

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i. e., a screen made from .040 mm diameter beads would have a limit of resolution around 25 lines/mm.

The patent does not give the optimum refractive indices between the glass beads and the embedding plastic for all of the light to be focused exactly at the back of the bead. Such a theoretical analysis follows.

Consider the glass bead shown in Figure 2. A ray of light is in-

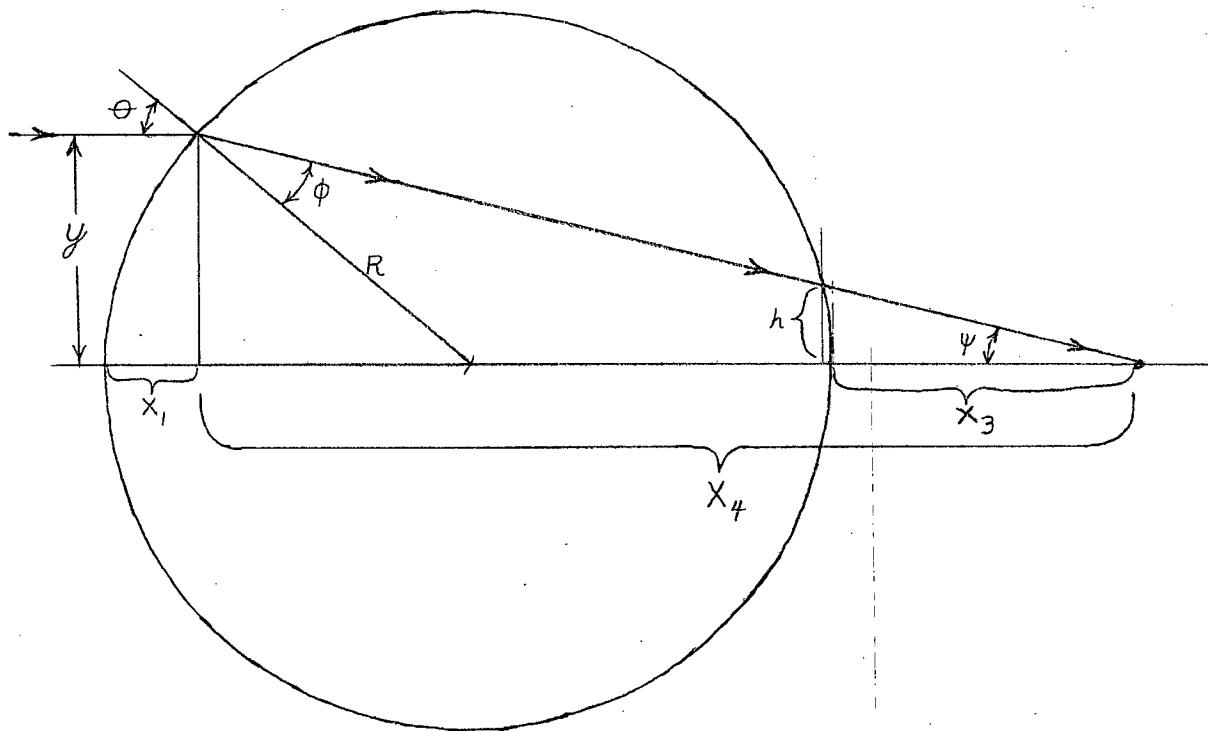


Figure 2. Geometry for Tracing Rays Through a Glass Bead

incident at a height y from the optical axis, and is focused near the back of the bead emerging at a height h from the optical axis. Ideally h is zero or very near so for all light rays. We now wish to determine L/R as a function of y/R and n_1/n_2 .

From geometrical considerations, h/R is given by

$$\frac{h}{R} = \frac{y}{R} \cdot \frac{2R - (x_1 + x_2)}{x_2}$$

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Without carrying through the mathematical details this has the final form,

$$\frac{h}{R} = A \left[1 - (1 + D) \cdot \left(\frac{C - BD}{CD + A^2 B} \right) \right] , \quad (1)$$

where

$$A = y/R ,$$

$$B = n_1/n_2 ,$$

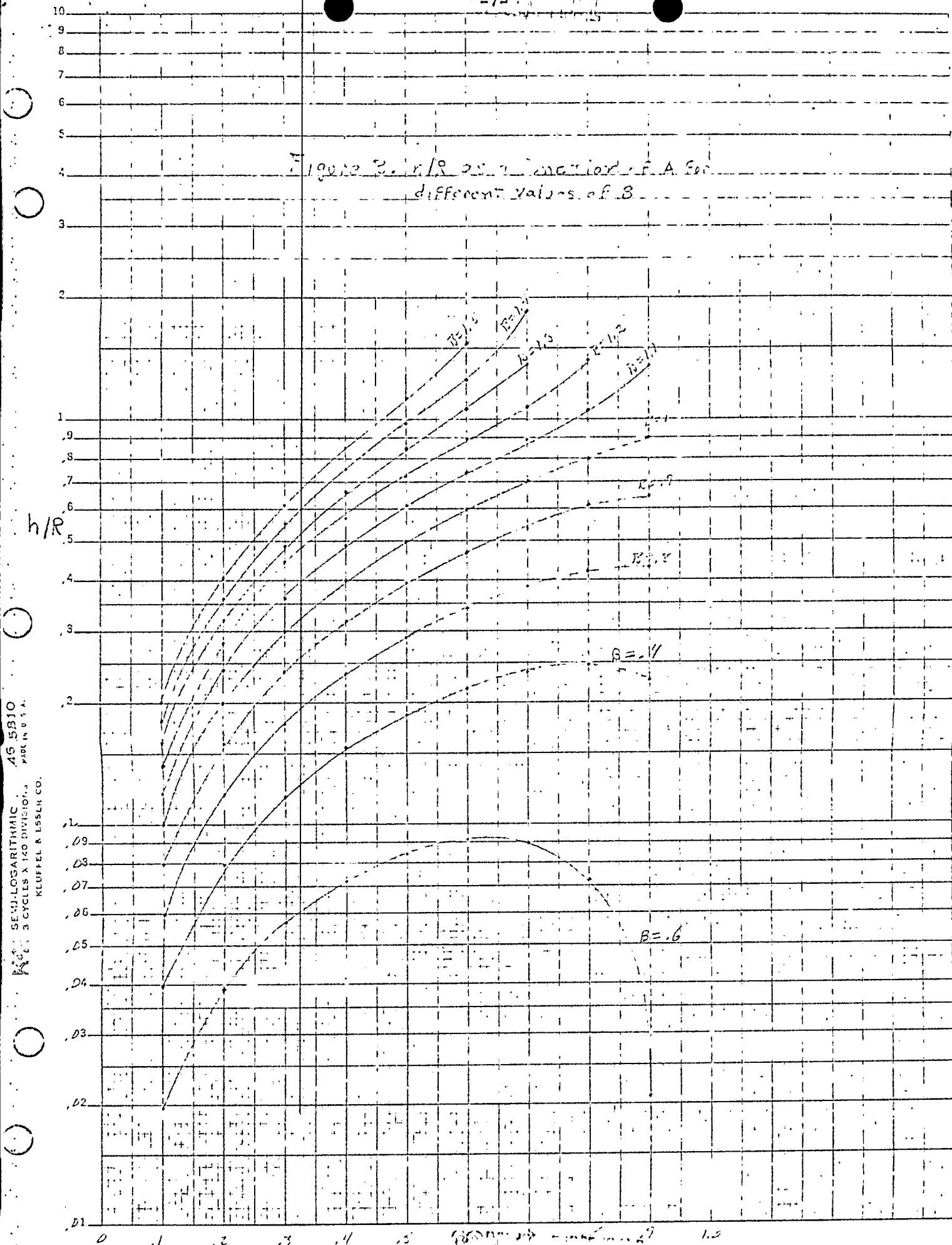
$$C = \sqrt{1 - A^2 B^2} ,$$

and

$$D = \sqrt{1 - A^2} .$$

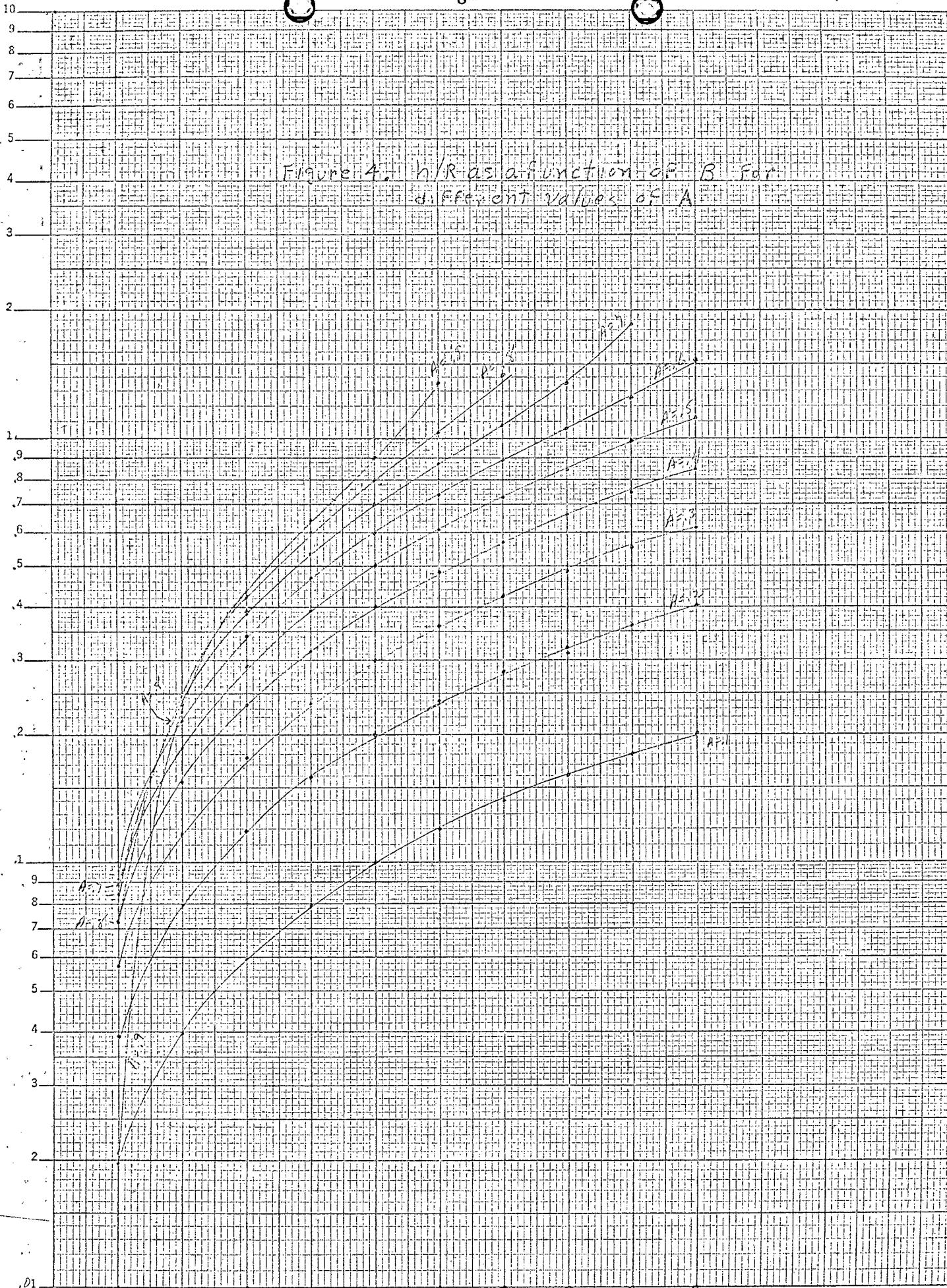
Equation (1) has been evaluated for values of A from 0 to 1 and B from .6 to 1.5. Figure 3 shows h/R as a function A for different values of B and Figure 4 is h/R plotted as a function of B for different values of A. Figure 3 is perhaps more useful. From this we can see that for B = .6 all of the incident energy will pass through a hole of diameter .1 h/R. Thus 99% of the viewing side of the screen will be covered by an absorbing material thereby making it very insensitive to ambient light. As B increases, the spot size at the back of the bead increases. Typical values of B lie between .8 and .95, and possibly as low as .7. For B greater than .6, the light comes to focus slightly beyond the back surface; however for B less than about .6, all rays come to focus inside the bead and spread apart again before reaching the surface. Values of h/R for B less than .6 were computed but not shown, because of the impracticality of having such high index beads.

Presently models of this particular screen are being fabricated for preliminary evaluation. Realistic screens will then be fabricated using 3 or 4 sizes of beads down to -150 mesh. The smallest beads have a diameter of 65 microns, and will have a resolution limit of 15 lines/mm.



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DATA APPENDIX A

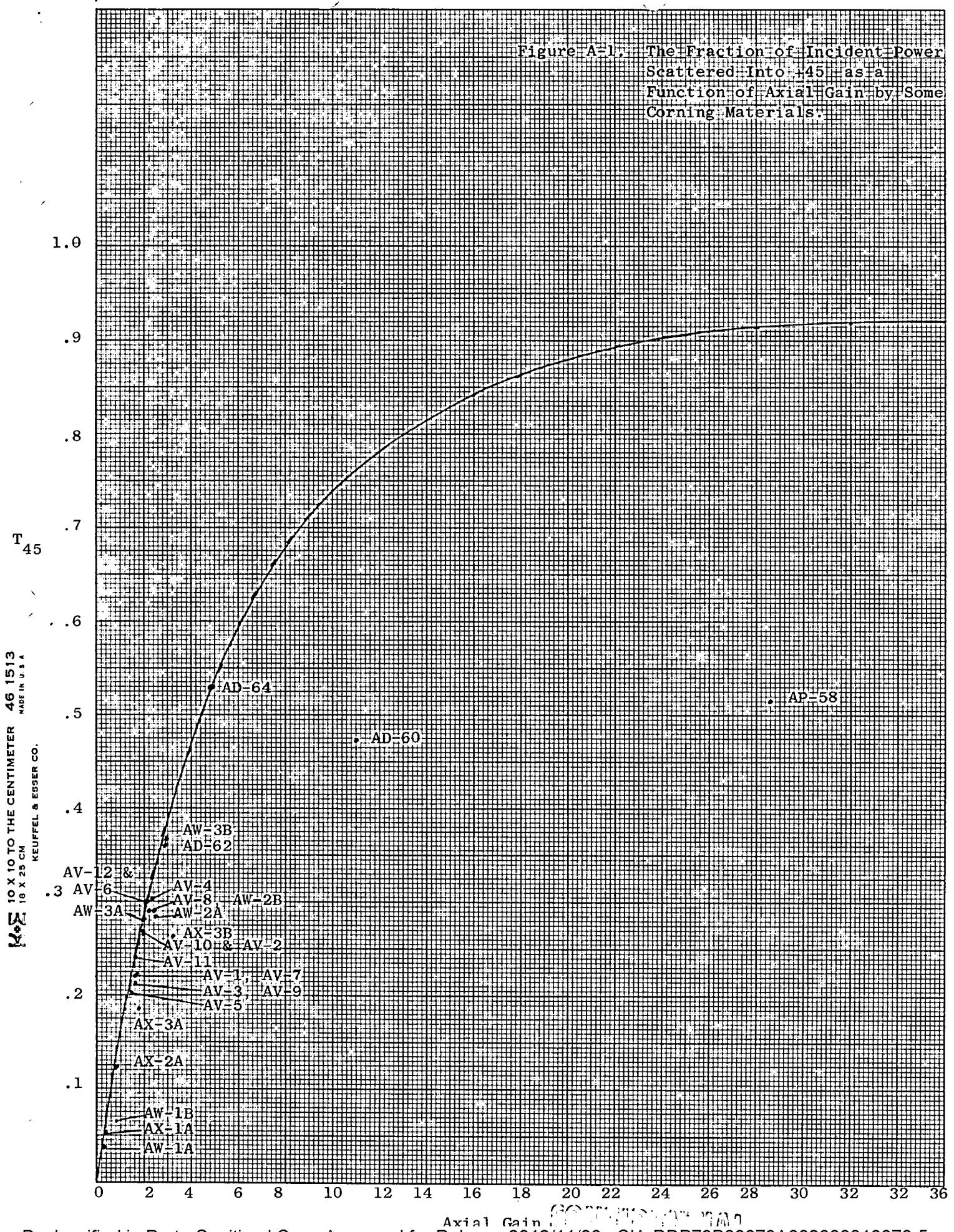
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Table I

SUMMARY OF THE OPTICAL PROPERTIES OF
SOME CORNING GLASS WORKS MATERIALS

<u>Sample Code</u>	<u>T_S %</u>	<u>T₄₅ %</u>	<u>T_{Spec} %</u>	<u>Axial Gain</u>	<u>Brightness Variation ± 45° (%)</u>	<u>Thickness (MM)</u>
AD-58	96	51	0.2	28.	85	.07
AD-60	96	47	0	11.	67	.111
AD-62	92	36	0	2.8	9	.418
AD-64	93	53	0	4.8	30	.249
AV-1	54	22	0	1.5	2	1.02
AV-2	73	26	0	2.0	6	.508
AV-3	57	21	0	1.6	7	1.07
AV-4	74	30	0	2.3	9	.507
AV-5	56	20	0	1.5	6	1.06
AV-6	78	30	0	2.1	2	.507
AV-7	57	22	0	1.6	6	1.04
AV-8	76	29	0	2.1	5	.508
AV-9	57	21	0	1.6	4.7	1.02
AV-10	72	27	0	1.9	4.2	.507
AV-11	64	24	0	1.6	1.6	1.02
AV-12	80	29	0	2.1	5.1	.507
AX-1A	13	5	0	0.4	2.8	.481
AX-2A	34	12	0	0.8	1.4	.491
AX-3A	54	19	36	1.8	18	.517
AX-3B	67	26	16	3.2	29	1.01
AW-1A	9	4	0.8	0.3	2	1.06
AW-1B	17	6	3.5	0.9	37	.564
AW-2A	69	28	1.1	2.4	12	1.05
AW-2B	74	29	3.4	2.4	11	.539
AW-3A	65	28	0	2.	3	1.06
AW-3B	82	37	0.3	3.	15	.55

Figure A-1. The Fraction of Incident Power Scattered Into +45° as a Function of Axial Gain by Some Corning Materials.



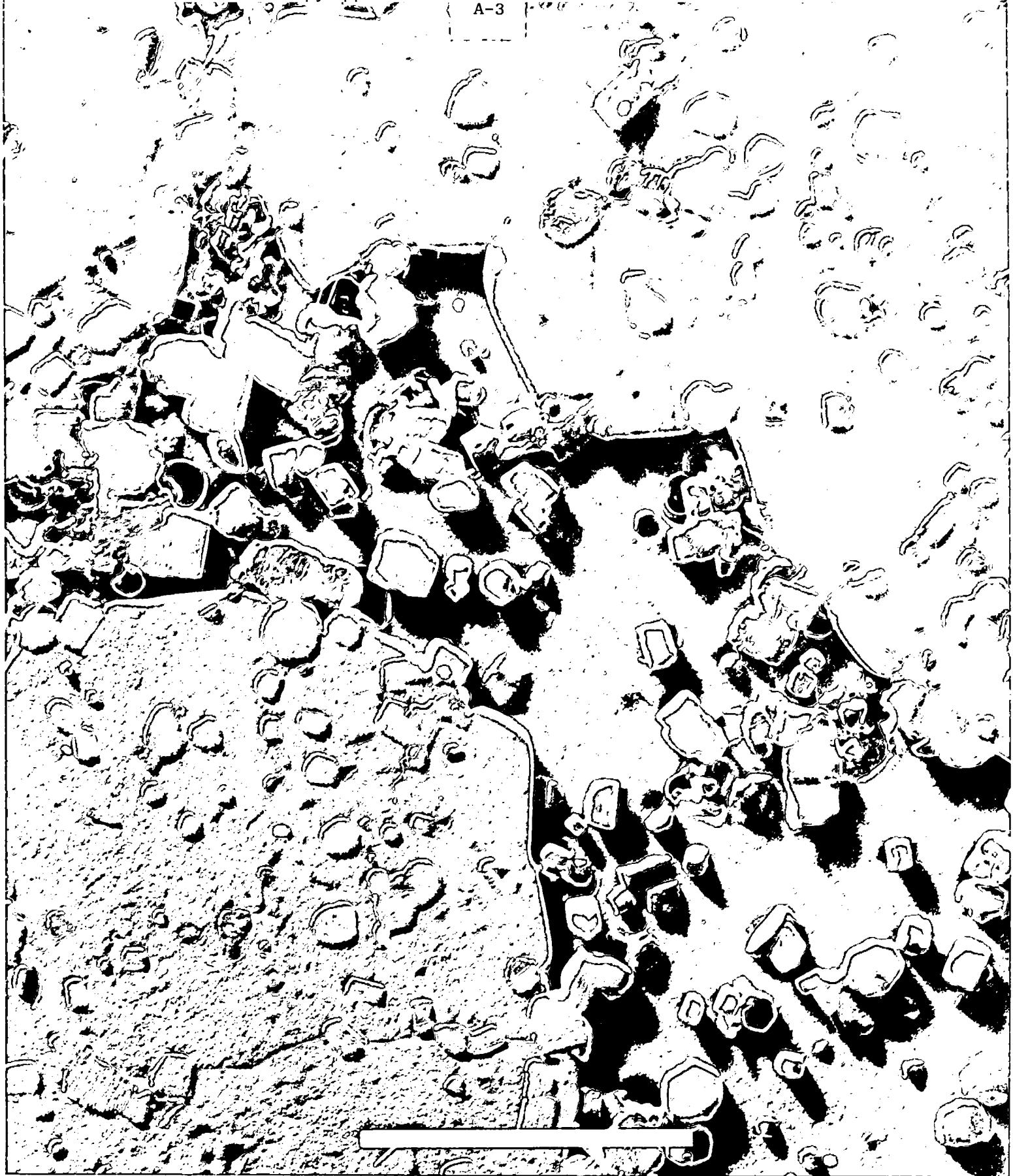


Figure A-2. Electron Micrograph Showing Scattering Centers of Sample AS-4

A-4

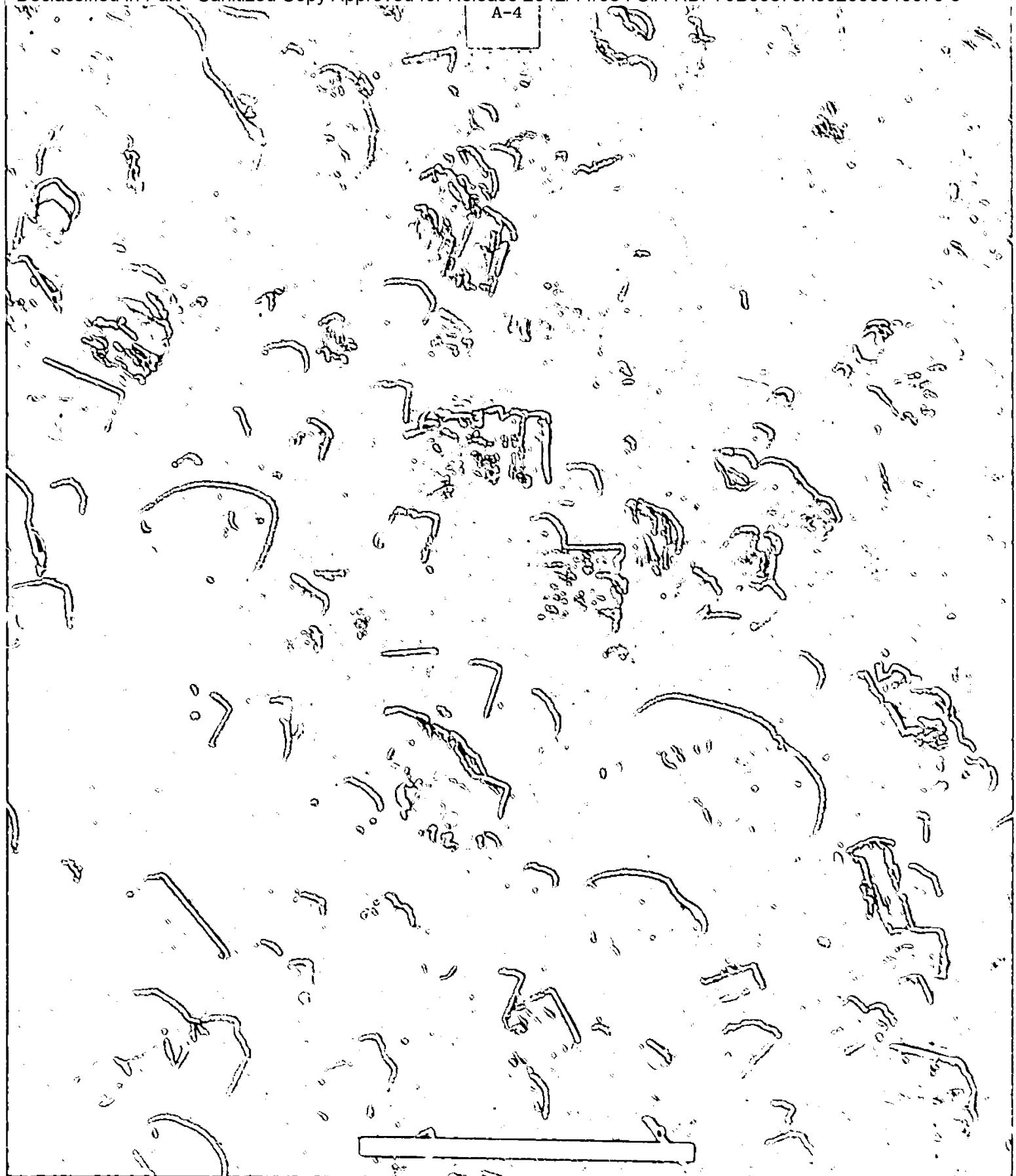


Figure A-3. Electron Micrograph Showing Scattering Centers of Sample AS-9

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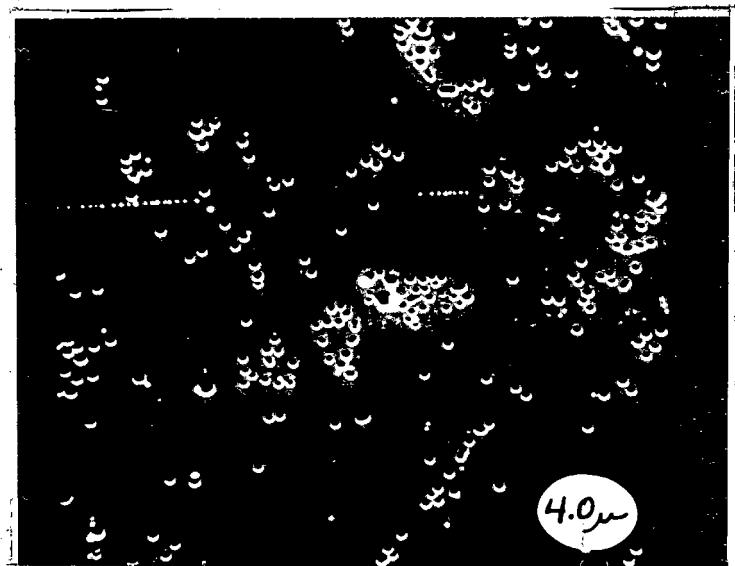
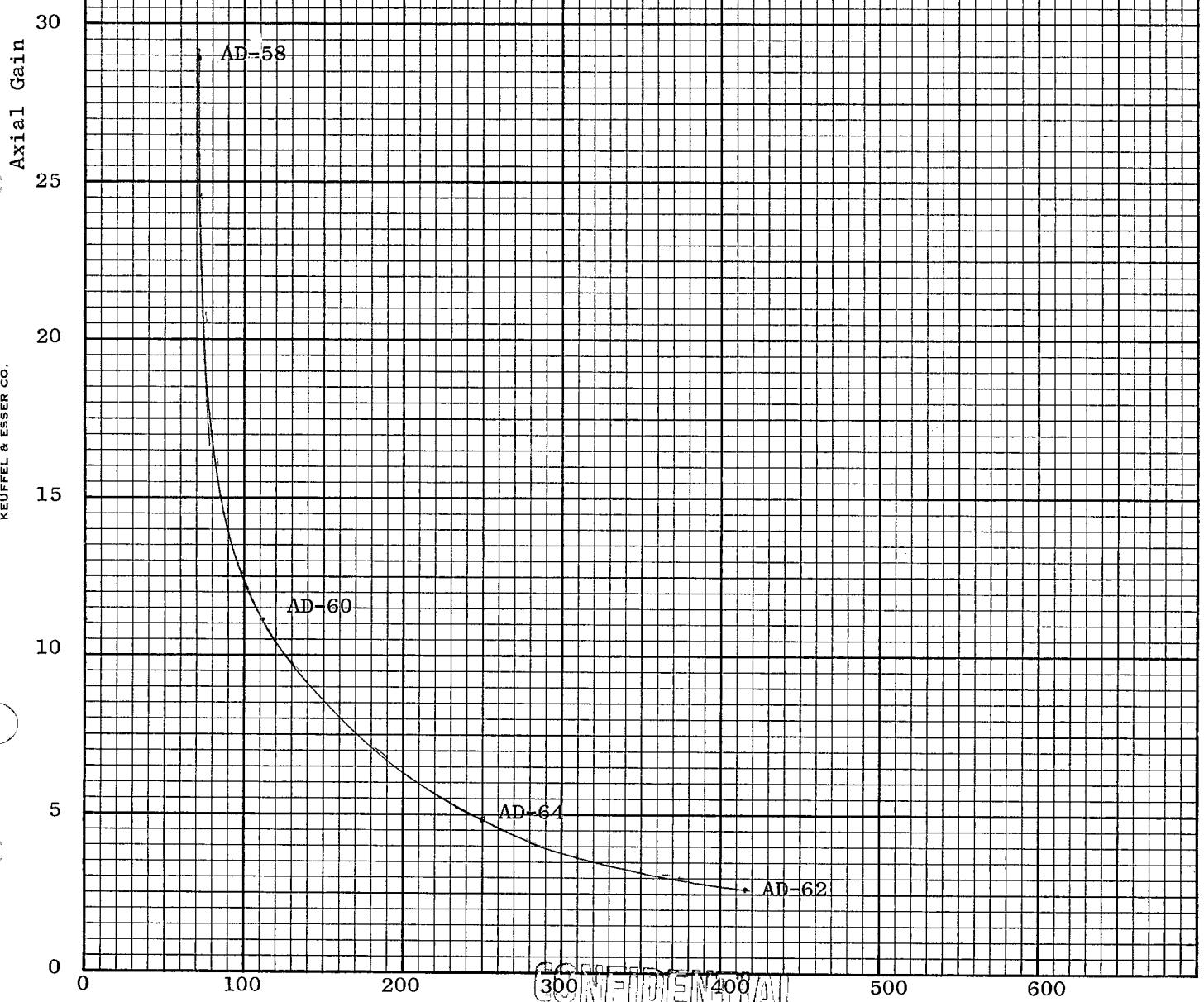


Figure A-4. Photo Micrograph of a Glass Containing High Index Particles

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Figure A-5. Plot of Axial Gain as a Function
of Scattering Layer Thickness
for Fotoform^R Glass.



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DATA APPENDIX B

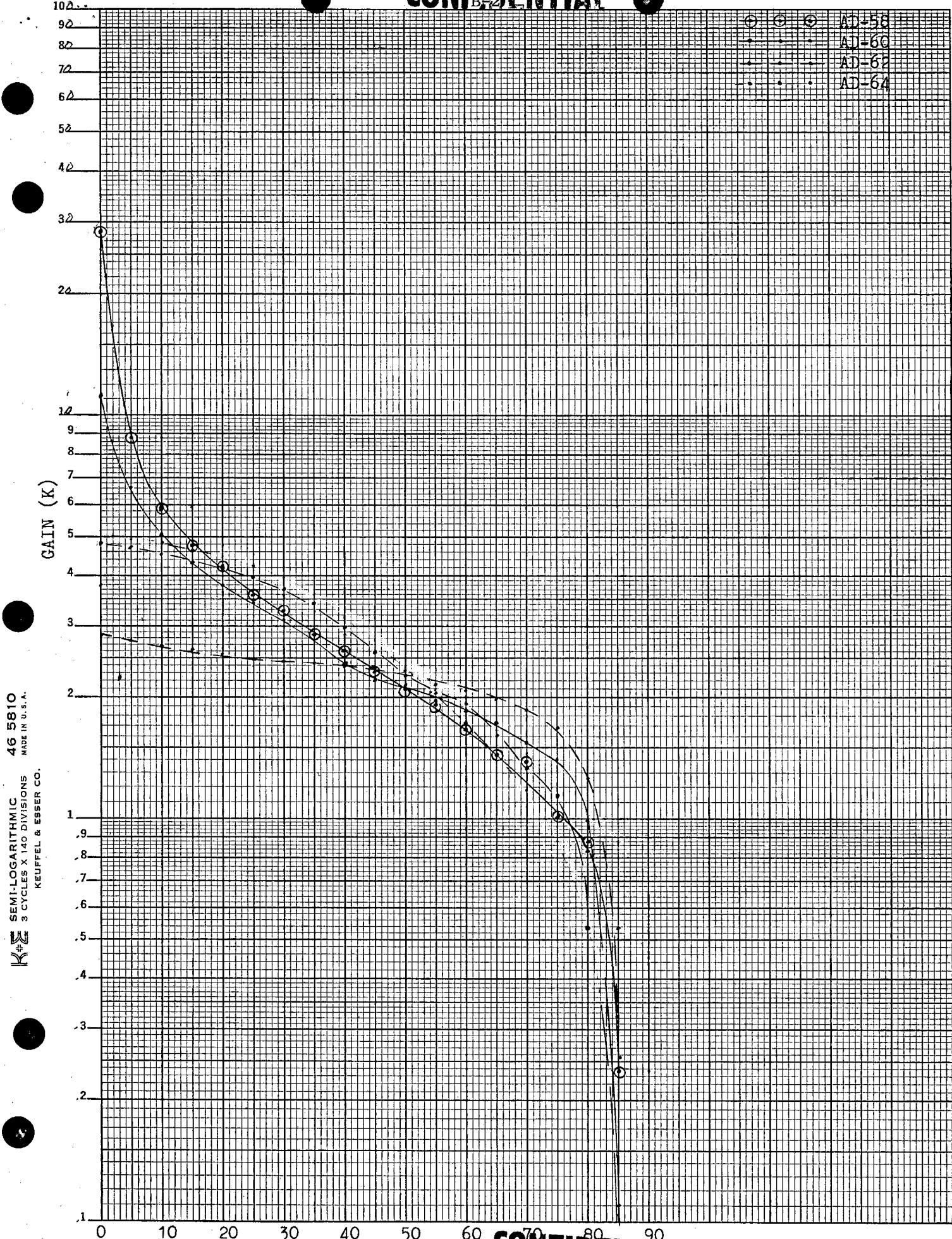
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SUMMARY OF ANGULAR GAIN FUNCTIONS.

ANGLE K	AD-58	SAMPLE CODES	AD-60	AD-62	AD-64
0	28.56		11.01	2.81	4.81
5	8.81		6.6	2.75	4.69
10	5.95		5.06	2.69	4.54
15	4.78		4.35	2.63	4.37
20	4.26		3.8	2.56	4.19
25	3.59		3.41	2.49	3.98
30	3.28		3.1	2.45	3.71
35	2.86		2.84	2.43	3.42
40	2.62		2.42	2.39	2.98
45	2.33		2.2	2.33	2.59
50	2.09		2.15	2.25	2.25
55	1.9		1.96	2.17	1.9
60	1.67		1.85	2.08	1.61
65	1.45		1.74	1.98	1.33
70	1.38		1.54	1.86	1.12
75	1.02		1.41	1.68	.83
80	.88		.99	1.25	.54
85	.24		.11	.25	.05
90	0		0	0	0
<hr/>					
TS	.9574		.957	.92	.93
T45	.515		.473	.362	.527
TSP	.0016		0	0	0
V45	.849		.667	.093	.3
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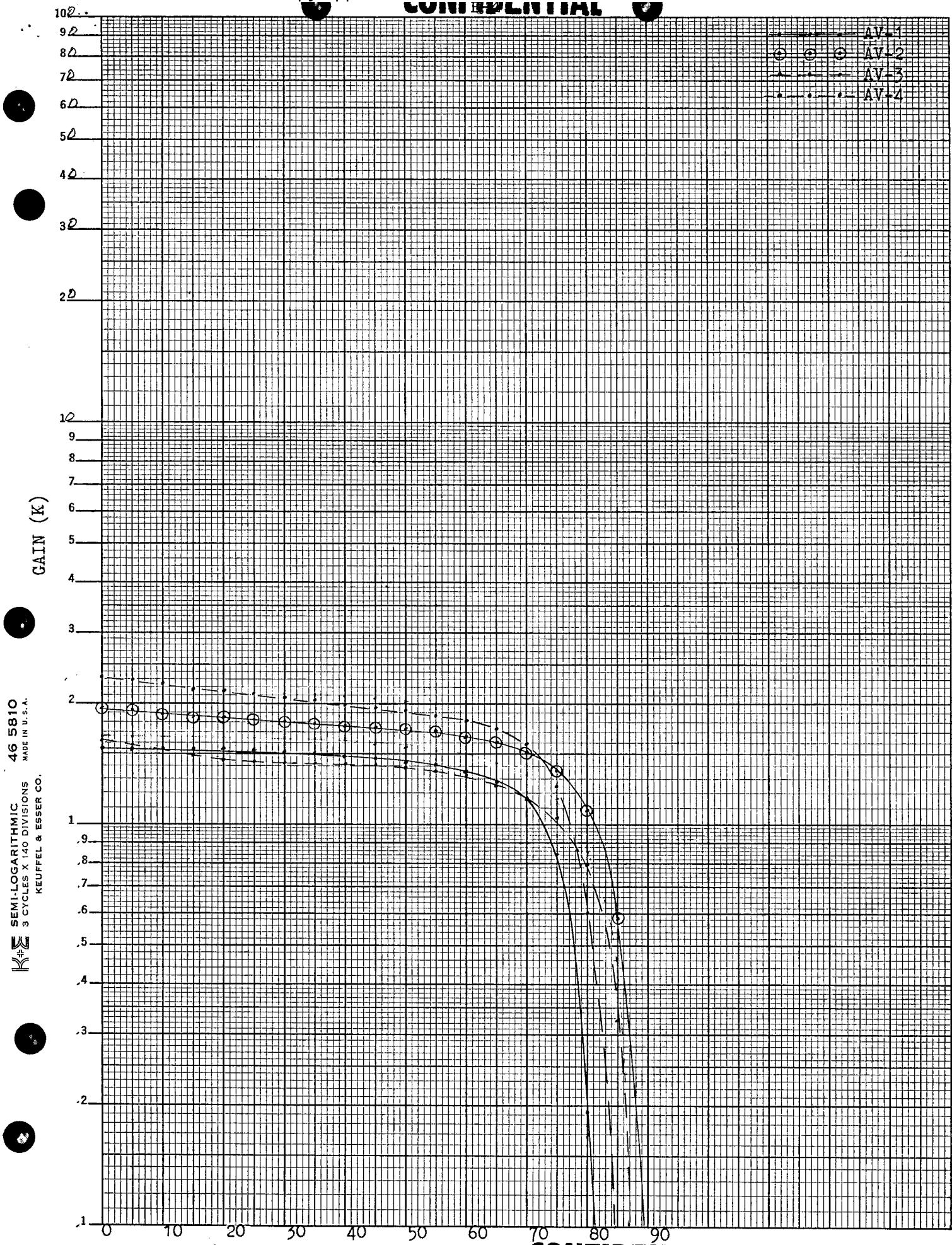
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SUMMARY OF ANGULAR GAIN FUNCTIONS..

ANGLE K	AV-1	AV-2	AV-3	AV-4
0	1.53	1.96	1.62	2.34
5	1.54	1.92	1.57	2.29
10	1.54	1.89	1.53	2.23
15	1.54	1.86	1.5	2.19
20	1.53	1.84	1.47	2.15
25	1.52	1.82	1.45	2.11
30	1.51	1.81	1.43	2.06
35	1.51	1.79	1.43	2.03
40	1.49	1.78	1.42	1.99
45	1.47	1.75	1.4	1.96
50	1.44	1.73	1.4	1.92
55	1.4	1.71	1.37	1.87
60	1.36	1.67	1.33	1.81
65	1.29	1.62	1.26	1.72
70	1.15	1.51	1.17	1.59
75	.85	1.36	1.03	1.25
80	.19	1.1	.8	.6
85	.0 3	.58	.32	0
90	0	0	0	0
<hr/>				
TS	.537	.73	.569	.745
T45	.221	.265	.212	.303
TSP	0	0	0	0
V45	.023	.056	.07	.089
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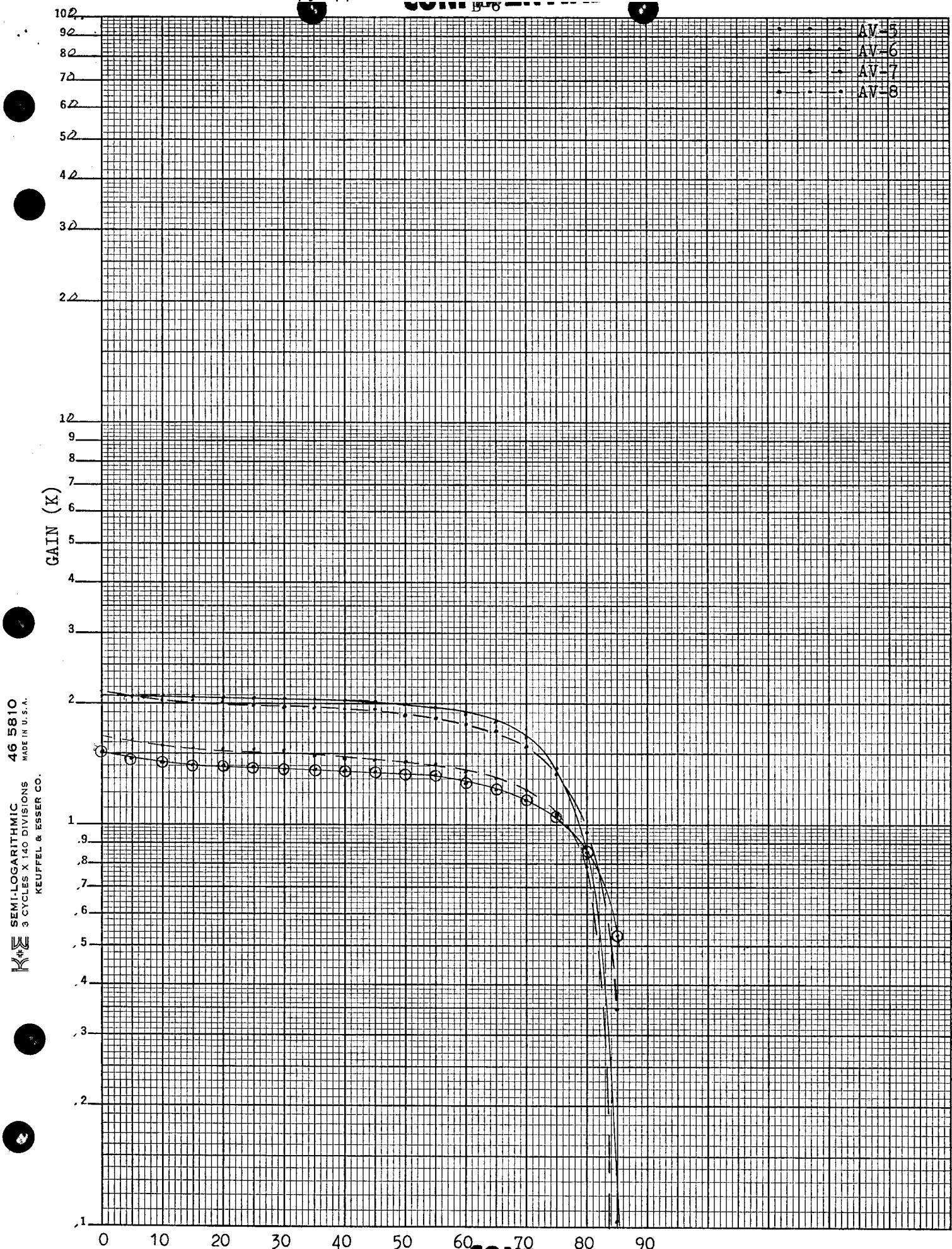


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SUMMARY OF ANGULAR GAIN FUNCTIONS.

ANGLE K	SAMPLE CODES			
	AV-5	AV-6	AV-7	AV-8
0	1.52	2.1	1.64	2.13
5	1.46	2.1	1.61	2.09
10	1.43	2.09	1.59	2.06
15	1.41	2.09	1.56	2.04
20	1.4	2.09	1.54	2.01
25	1.4	2.07	1.53	1.99
30	1.39	2.06	1.51	1.97
35	1.38	2.05	1.49	1.96
40	1.37	2.04	1.48	1.94
45	1.36	2.02	1.46	1.91
50	1.33	2	1.43	1.89
55	1.31	1.96	1.41	1.85
60	1.28	1.9	1.37	1.79
65	1.23	1.81	1.3	1.71
70	1.16	1.65	1.21	1.57
75	1.04	1.38	1.05	1.33
80	.85	.82	.78	.96
85	.53	.1	.05	.35
90	0	0	0	0
=====				
TS	.564	.778	.575	.76
T45	.203	.301	.221	.289
TSP	0	0	0	0
V45	.056	.019	.061	.054
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SUMMARY OF ANGULAR GAIN FUNCTIONS.

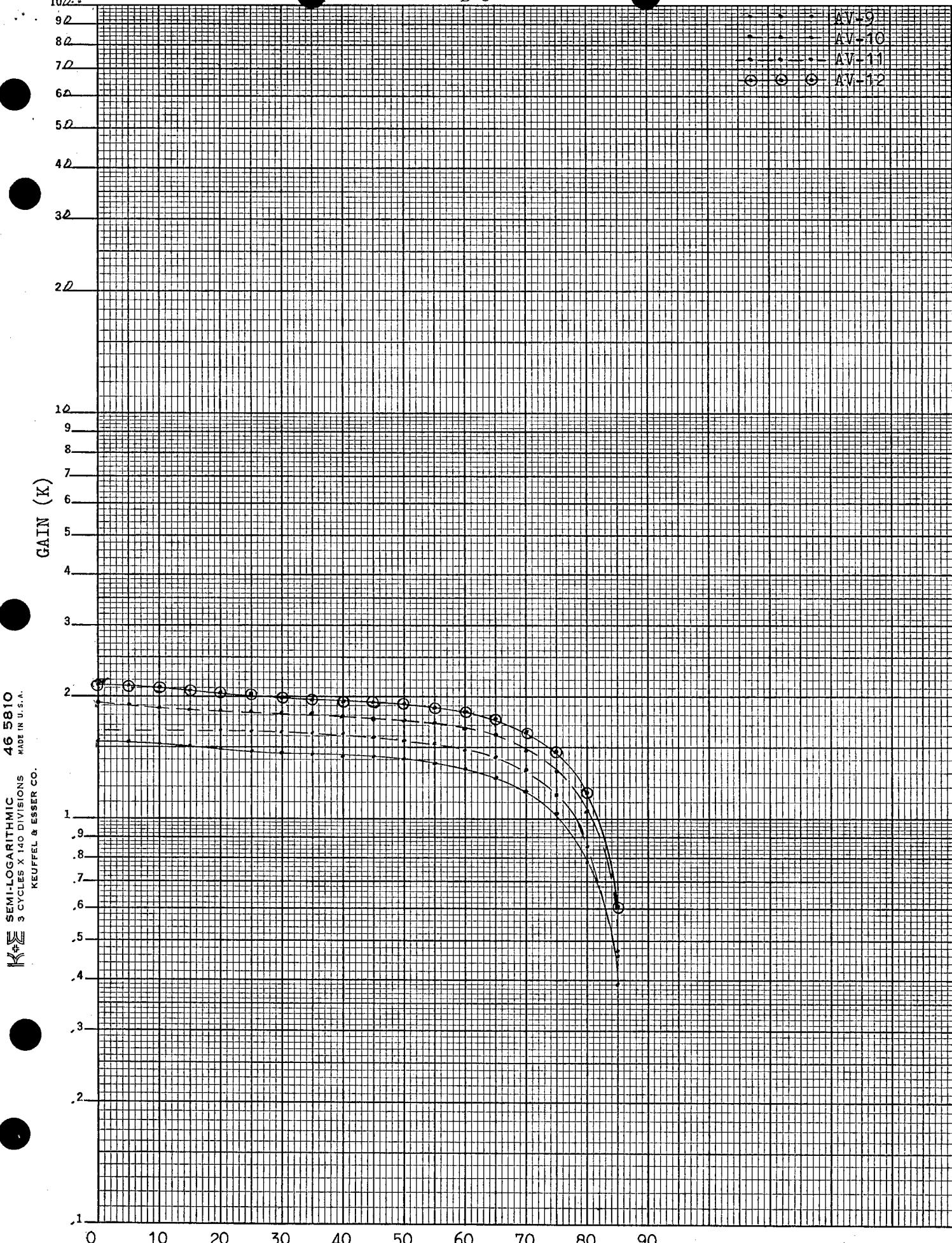
ANGLE	SAMPLE CODES			
	AV-9	AV-10	AV-11	AV-12
0	1.56	1.92	1.65	2.14
5	1.54	1.9	1.65	2.12
10	1.53	1.89	1.65	2.1
15	1.51	1.87	1.65	2.07
20	1.49	1.85	1.65	2.04
25	1.48	1.84	1.65	2.02
30	1.47	1.83	1.64	1.99
35	1.45	1.81	1.63	1.97
40	1.44	1.79	1.62	1.95
45	1.42	1.77	1.6	1.93
50	1.4	1.75	1.57	1.9
55	1.37	1.72	1.54	1.87
60	1.32	1.67	1.49	1.83
65	1.27	1.6	1.42	1.76
70	1.17	1.48	1.32	1.64
75	1.04	1.31	1.16	1.46
80	.78	1.04	.86	1.15
85	.39	.47	.43	.6
90	0	0	0	0
<hr/>				
T8	.575	.722	.649	.796
T45	.215	.267	.239	.292
TSP	0	0	0	0
V45	.047	.042	.016	.051
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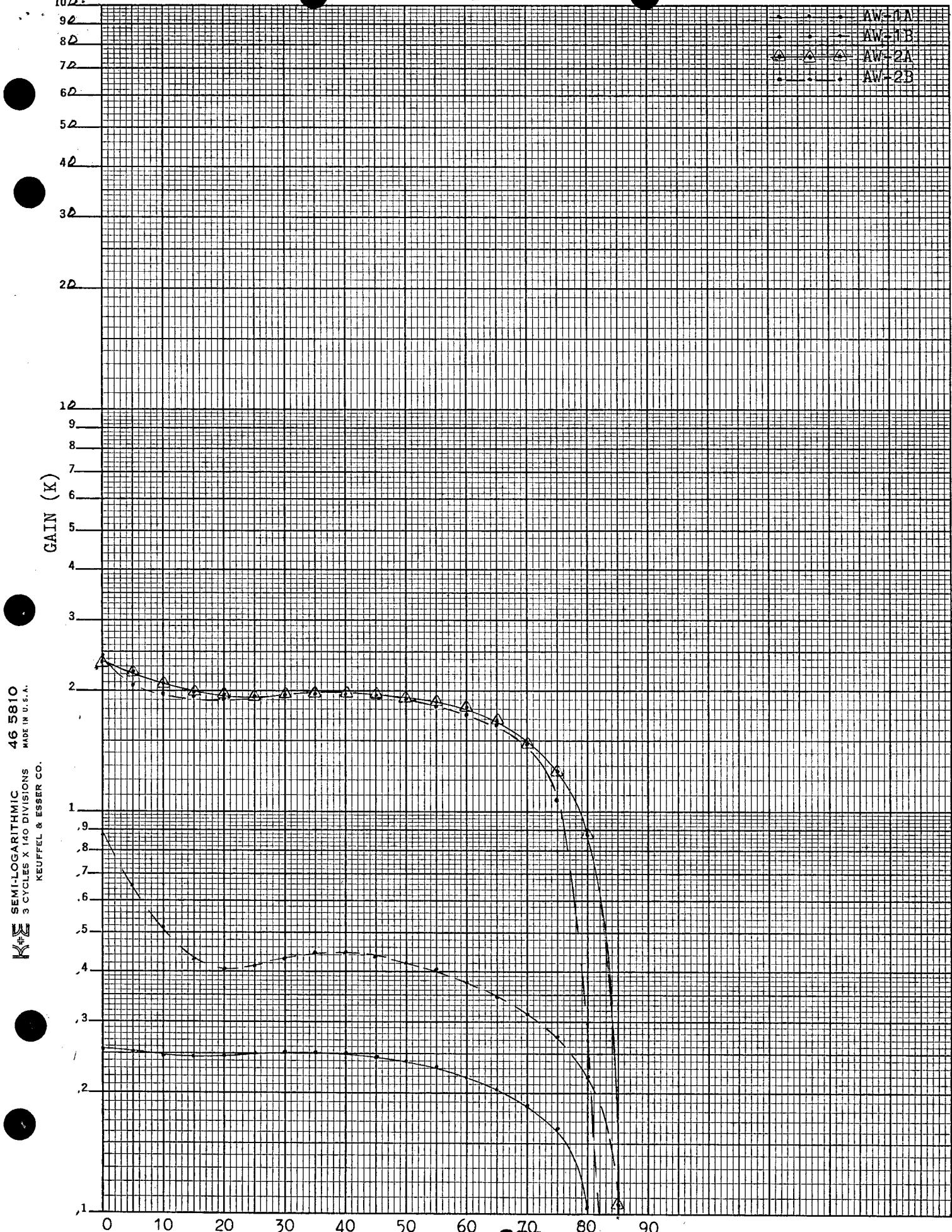
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SUMMARY OF ANGULAR GAIN FUNCTIONS.

ANGLE K	SAMPLE CODES			
	AW-1A	AW-1B	AW-2A	AW-2B
0	.2 6	.88	2.45	2.38
5	.2 5	.66	2.07	2.23
10	.25	.52	1.97	2.1
15	.25	.43	1.92	2
20	.2 5	.41	1.92	1.94
25	.25	.42	1.93	1.92
30	.25	.43	1.95	1.96
35	.25	.45	1.95	1.97
40	.25	.44	1.95	1.96
45	.25	.44	1.94	1.94
50	.24	.42	1.9	1.92
55	232	.4	1.84	1.88
60	.22	.38	1.76	1.81
65	.2	.35	1.65	1.69
70	.19	.31	1.48	1.5
75	.16	.27	1.08	1.26
80	.1	.22	.27	.88
85	0	.1	.04	.11
90	0	0	0	0

TS	.0921	.1663	.6952	.7423
T45	.037	.065	.285	.288
TSP	.0079	.0355	.0108	.0337
V45	.022	.368	.121	.106
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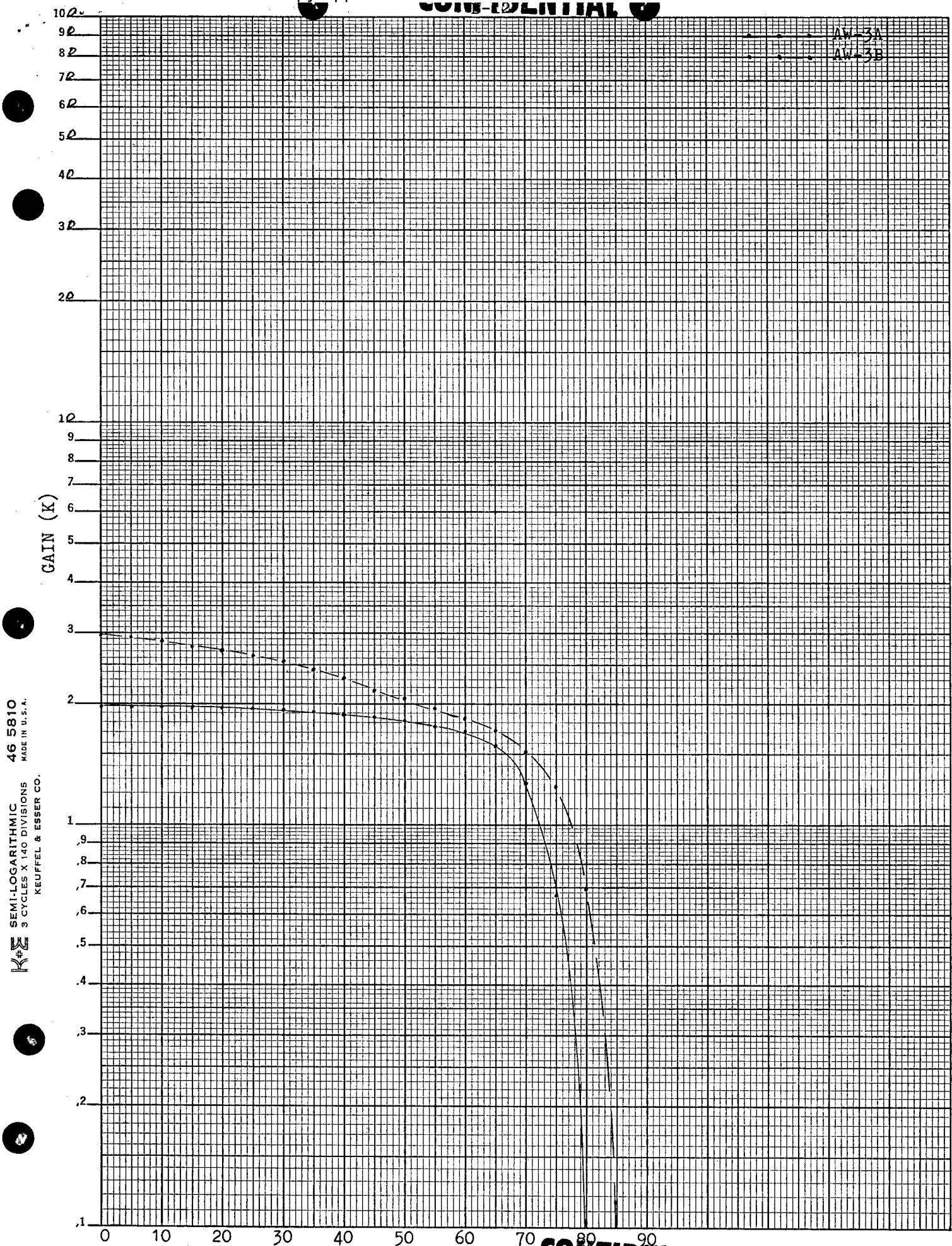
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SUMMARY OF ANGULAR GAIN FUNCTIONS.

ANGLE K	SAMPLE CODES			
	AW-3A	AW-3B	0	0
0	1.98	2.98	0	0
5	1.97	2.92	0	0
10	1.97	2.86	0	0
15	1.97	2.78	0	0
20	1.96	2.71	0	0
25	1.94	2.63	0	0
30	1.93	2.54	0	0
35	1.91	2.43	0	0
40	1.88	2.31	0	0
45	1.85	2.18	0	0
50	1.81	2.08	0	0
55	1.77	1.95	0	0
60	1.7	1.82	0	0
65	1.58	1.7	0	0
70	1.26	1.5	0	0
75	.67	1.24	0	0
80	.1	.69	0	0
85	.04	.09	0	0
90	0	0	0	0
<hr/>				
TS	.6457	.8246	0	0
T45	.281	.368	0	0
TSP	.0003	.0034	0	0
V45	.033	.155	0	0
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SUMMARY OF ANGULAR GAIN FUNCTIONS.

ANGLE	SAMPLE CODES			
	AX-1A	AX-2A	AX-3A	AX-3B
0	.36	.83	1.78	3.18
5	.36	.83	1.41	2.27
10	.3 6	.83	1.31	1.87
15	.36	.83	1.26	1.77
20	.36	.83	1.24	1.75
25	.3 6	.84	1.24	1.75
30	.35	.84	1.25	1.77
35	.35	.85	1.27	1.79
40	.35	.85	1.29	1.81
45	.34	.85	1.31	1.8
50	.34	.84	1.31	1.79
55	.33	.83	1.31	1.76
60	.32	.81	1.29	1.72
65	.3	.76	1.26	1.65
70	.28	.69	1.19	1.52
75	.2 5	.59	1.08	1.11
80	.18	.47	.82	.28
85	.01	.23	.44	.02
90	0	0	0	0
<hr/>				
TS	.1342	.338	.545	.6656
T45	.052	.123	.186	.263
TSP	0	0	.365	.1634
V45	.028	.014	.178	.29
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